CHAPTER 3

STUDY 2

Gait Performance during Gait Initiation and Termination while Dual-tasking in Individuals with Mild Cognitive Impairment

3.1 Introduction

Traditionally, walking has been considered to be simple automatic motor behaviors that involve little or no cognitive function. However, recent evidence indicates that walking is not an automatic action but involves cognitive function. In line with this notion is the findings that individuals with cognitive impairment such as AD had a significant gait changes and higher prevalence of falls than those without AD (105). The rate of falls was almost three times of their age-matched, non-demented elders (106-110). Because most falls occurred during walking, gait changes have been identified as a major risk factor for falls in both elders with and without AD (109, 111).

Approximately 114 million elderly worldwide is estimated to have AD by the year 2050 (1). Although AD cannot be cured, promising evidence that early intervention can delay the disease progression emphasizes the need to identify people with pre-dementia stage. A field of ageing and dementia has now focused on people who are at the transitional state between normal ageing and early dementia known as MCI (103, 112). Although the clinical hallmark of MCI is cognitive impairment, recent studies have shown that individuals with MCI also demonstrate gait change related to fall such as slower walking speed and shorter stride length compared to non-cognitive impaired elders (14, 15, 113). However, previous works have revealed that gait patterns in individuals with MCI are not different from cognitively intact controls (16, 17). Discrepancies in findings among previous studies may be due to the variations in walking tasks. It is possible that gait impairment in people with MCI may be undetected during performance of a steady, unchallenging walking condition.

To reveal impairments in gait in this population, a challenging walking condition may be needed.

Gait initiation and termination are considered to be the complex transition phase due to the increased stability challenges during these transitional phases (18). Thus, first sign of gait disorders may be detected in these phases. Moreover, recent works have suggested that performing a simple dual-task has an adverse effect on gait performance in individuals with AD (98, 109). One possible explanation is that deficits in the ability to divide attention and/or to properly allocate the resources between concurrent tasks may compromise walking stability in individuals with AD. Exploring gait characteristics in challenging condition such as adding secondary task during gait initiation and termination may reveal gait dysfunctions in individuals at pre-dementia stage as MCI. Therefore, this study aimed to investigate gait performance of individuals with MCI during gait initiation and termination under both single- and dual-task conditions. If gait changes can be identified at early stage, an early intervention aims to prevent future fall may be achieved.

3.1.1 Research questions, purposes and hypotheses of the study

Research question

How does gait performance during gait initiation and termination of individuals with MCI differ from those cognitively intact controls under single- and dual-task conditions?

Purposes

1) To compare gait performance during gait initiation between individuals with MCI and cognitively intact controls under single- and dual-task conditions.
2) To compare gait performance during gait termination between individuals with MCI and cognitively intact controls under single- and dual-task conditions.

Hypotheses

During gait initiation

Gait deterioration (i.e. shorter step length, longer step time, wider step width and greater spatiotemporal variabilities) will be more pronounced in individuals with MCI than that of cognitively intact controls under the dual-task condition.

During gait termination

Gait deterioration (i.e. require more steps to stop, take longer stopping time and stopping distance) will be more pronounced in individuals with MCI than that of cognitively intact controls under the dual-task condition.

3.2 Literature Reviews

3.2.1 Gait initiation and termination studies

Effective gait consists of two fundamental components. The first component involves the ability to generate or sustain continuous movement and the second component covers the capable in maintaining gait stability during forward progression (114). Gait stability can be compromised during the transition from one state (either statically stable or dynamically stable) to another state. Therefore, the epidemiological studies of fall in elders were reported that about 50% of the falls occur when they walk only short distances or/and during some form of locomotion as avoiding the obstacles, bumping into people and objects, changing the direction, specifically, initiating and terminating gait where the body suddenly shifts to the acceleration and deceleration period, respectively (115). To better understand the strategies being employed during performing a gait task, recent research has included an examination of various gait sub-tasks that may compromise stability.

Gait initiation is defined as a transient phase between standing and walking which is characterized by preparatory (the phase lasts from onset until the toe-off phase of the first swing foot) and stepping phases (the phase occurs when person lifts the first swing foot from the floor), respectively (116). The initiation phase challenges the human balance control system to initiate internal perturbations by forcing an individual from a state of stable balance to a continuously unstable posture during walking. In this situation, the body needs to accelerate the Center of Mass (COM) forward and towards the stance limb to permit the swing limb to lift (117). The initiation of gait is governed by a motor program performed through a stereotyped pattern of muscle activity and invariant relative timing among particular muscles (117, 118). Previous studies have shown that the variability during gait initiation increases in elderly people. Mickelborough et al (116) found that the onset of muscle activity patterns during the preparatory phase were more variable in healthy elders compared to those previously reported in young adults. Further, Mbourou et al (119) found that elderly fallers demonstrated shorter first step lengths during gait initiation compared to elderly non-fallers and young adults. It is also evident that impaired cognition is related to an increased timing variability during gait initiation. Wittwer et al (18) found that patients with dementia (mild to moderate AD) showed greater variability in second step time during gait initiation than healthy elders. Together, evidence from previous works suggests that step length and step time of the first and second steps can be used as indicators for a decline in motor control. In this present study, we also additionally examined step width because previous study suggested step width reflects balance-control mechanism (120). This parameter may indicate an impairment of balance control in individuals with MCI.

Gait termination is defined as a transient period from repetitive gait (steady state gait) to a full stop (postural stance) (121). Termination of gait in the everyday environment may be associated with avoiding obstacles or boundaries prior to which forward momentum must be arrested. Stopping is a great challenge to the body as the nervous system must effectively change the body from a dynamic to a static state (122). To safely terminate gait, the COM must be maintained within a step length. However, if the COM exceeds the upper boundary regions, the body may not provide sufficient time to decelerate the COM and an additional step would be required to maintain stability (112, 121). Previous studies have shown that the number of additional steps (the number of steps required to stop walking), stopping time and distance in elders was different from those in young adults (123, 124). Specifically, elderly subjects required more steps (i.e. two or three steps) to stop, which resulted in an increased total stopping time and total distance compared to young adults who usually only required one step to stop. Together, evidence from previous works suggests that the number of additional steps as well as the total step length and total step time can be used as indicators of a decline in the gait control mechanism to deal with instability during gait termination.

3.2.2 Dual-task related gait changes in individuals with cognitive impairment

Current understanding of dual-task paradigms is derived from two main neuropsychological theories; the capacity-sharing theory and the bottleneck theory. The capacity-sharing theory states that humans have limited attentional resources, so that when people carry out two tasks concurrently and one or both tasks require attention exceeding available resources, performance of one or both tasks will decline (125). The bottleneck theory states that if two tasks share the same cognitive processors, the processing of the second task will be delayed until the networks are free from the processing of the first task (125).

Commonly, dual tasking relies upon executive function and the ability to allocate or divide attention (126, 127). Executive function commonly refers to a set of higher cognitive processes that control the allocation of attention between two tasks when performed simultaneously (127). Attention is one of the dynamic executive functions driven by sensory perception. In general, there are 3 types of attention: 1) selective attention (referred as the ability to focus on a single stimulus while ignoring irrelevant stimuli) 2) sustained attention (referred as the ability to maintain of focused attention over an extend period of time) and 3) divided attention (referred as the ability to focus on several relevant stimuli simultaneously) (128). Substantial evidence indicates that the ability to divide attention diminishes with advancing age. For elderly persons, walking while performing an attention-demanding task compromises gait performance (129, 130).

A dual-task paradigm is often used to examine the effect of a secondary task on gait among cognitively impaired persons. Consistent findings reveal that while walking and performing attentional-demanding task, AD patients exhibit significant gait changes compared to when walking without a secondary task (98, 109). One explanation is that gait control requires more attentional resources in AD patients. Combining a cognitive task with walking may create a competitive demand for executive functions that influence gait control efficiency (131). Visser et al (109) found that walking speed in AD patients decreased while walking when performing a verbal task (reciting name), suggesting that AD patients showed a deficit in dividing attention while performing two concurrent tasks. Sheridan et al (98) found that variability of stride time increased and gait speed decreased significantly while performing a relatively simple dual-task (repeating a random digit) as compared to walking task alone. Interestingly, researchers found that poor performance on standard neuropsychological tests such as MMSE, verbal fluency, and clock drawing were associated with an increased variability of gait timing when walking with divided attention. In addition, Allali et al (132, 133) found that stride time variability in patients with dementia increased during walking while counting forward and backward compared to usual walking. These findings suggest that as cognitive function declines, the ability to maintain a stable gait pattern while performing dual-task decreases in parallel.

Gaining an insight into the interaction between gait and cognition among people with MCI may be beneficial for providing an early detection approach. The dual-task paradigm is one of the methods that often used to investigate the interaction between cognition and gait among this population. The evidence from a limit number of studies reveals that variability of stride time increases significantly when dual tasking (i.e. counting backward, carrying a glass of water, naming animals and subtracting serial sevens) as compared to walking alone (134). It has been demonstrated that as difficulty of the cognitive task increases, the variability in gait while performing dual task increases in concert. Maquet et al (14) found that MCI participants showed slower walking speed and shorter stride length while performing a dual-task condition (i.e. counting backward) as compared to walking task alone. In addition, Montero-Odasso et al (96) were interested to assess the effect of specific cognitive domain on gait velocity during dual-task condition (i.e. counting backwards). The results demonstrated that under dual-task conditions, individuals with MCI had slower gait speed than single-task condition. These findings suggest that the specific cognitive domains, especially working memory may play an essential role in gait control among MCI persons.

3.2.3 Gait performance related to cognitive function

Recent evidence indicates that walking under usual circumstances also requires the integration of higher cognitive functions including attention, planning, memory, perception and other motor functions (135, 136). Therefore, cognitive decline would disrupt normal walking. Guo et al (137) found that mobility of the lower and upper extremities was actively involved with temporal lobe region activity. In addition, a recent PET study showed an association between higher activity in brain regions (especially the hippocampal region) and increasing complexity of a gait task (e.g. walking in a constraint environment) (138).

The hippocampus has a functional relationship with Prefrontal cortex (PFC), mediated through the entorhinal cortex (E) and the nigrostriatal system (NS) (139) (Fig1). Recent preclinical studies suggest that during walking, the hippocampus and parahippocampal regions play an essential role in spatial encoding and working memory (necessary for sequential ordering of movement) by detecting the incoming sensory input and then comparing it with previously stored information (perceptual-motor integration) (140, 141). Therefore, degeneration of the hippocampus causes a disintegration of sensory (visual, vestibular, and proprioceptive system) and contextual information into a spatial map, leading to gait disturbances. In addition, a recent MRI study showed a significant atrophy of the hippocampal and entorhinal regions in MCI elders compared with cognitively intact elders (62). Furthermore, the PFC is not only known for its role in executive functions such as attention and working memory, but also for its role in gait by its connection with the striatum and hippocampus. Thus, damage of the PFC may cause executive dysfunction, resulting in gait disturbances (142).

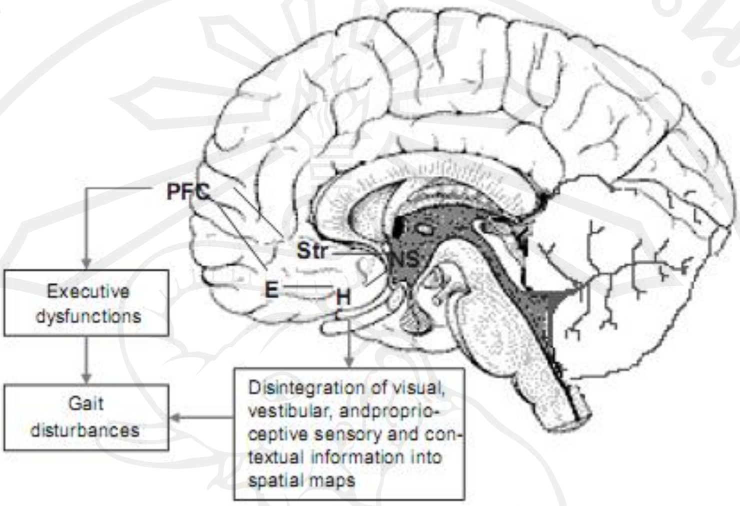

Figure 1 The hippocampus (H), prefrontal cortex (PFC), entorhinal cortex (E), nigrostriatal system (NS), striatum (Str) (105)

Brain areas that are at a long distance from each other are functionally connected via periventricular white matter (143). Periventricular white matter plays a crucial role in neuronal circuits such as cortico-cortical circuits (e.g. fronto-hippocampal circuit) and cortico-subcortical circuits, such as the fronto-striatal system. Thus, disruptions of the periventricular white matter fibers would result in disconnections of cortical circuits. Recent evidence from MRI study shows that elderly individuals with MCI demonstrate a degradation of periventricular white matter fibers. Stoub et al (63) suggest that, in addition to hippocampal atrophy, disruption of parahippocampal white matter fibers contribute to memory decline in MCI patients by partially disconnecting the hippocampus from incoming sensory input. Disruption of sensory information to the hippocampus may also compromise multimodal sensory input integration which is essential for gait performance.

3.2.4 Neuropsychological test for the determination of cognitive profiles

Neuropsychological tests are used to examine a variety of cognitive abilities including memory, attention, executive function, language, visuospatial function, and speed of information processing. Information of a person's cognitive abilities is necessary for distinguishing between amnestic and nonamnestic, and single-and multiple domains MCI can be obtained by administering specific neuropsychological tests (144). The widely used neuropsychological tests include 1) the Rey Auditory Verbal Learning Test and Wechsler Memory Scale (logical memory test: delayed recall) for examining episodic memory, 2) the Digit span forward-backward for examining attention, 3) the Trail Making Test part B-A, Serial 3 subtractions test, Stroop Color test and Wisconsin Card Sorting Test for examining executive function, 4) the Boston naming test and Semantic fluency test (e.g. animals and words beginning with particular alphabets for examining language ability), 5) the Clock drawing test, Block design and Rey-Osterrieth Complex Figure Test for examining visuospatial function, and 6) the Trail Making Test part A and Digit symbol coding test for examining speed of information processing (41, 144, 145).

For descriptive purpose, in this study, each participant's cognitive functions (i.e. episodic memory, attention, executive function, language ability and visuospatial function) were evaluated using five standard neuropsychological tests. Firstly, the Logical Memory-Delayed Recall, a subtest of the Wechsler Memory Scale was used to examine the participant's episodic memory (88). Secondly, the Digit Span forward-backward test, a subtest of the standard Wechsler batteries was used to examine the participant's attention (89). Thirdly, the Trail Making Test B-A, a subtest of Halstead Reitan battery, was used to examine the participant's executive function (90). Fourthly, Word Fluency (animal naming), a subtest of Delis-Kaplan Executive Function System, was used to examine the participant's language ability (146). Finally, Block Design, a subtest of Wechsler Adult Intelligence Scale was used to examine the participant's visuospatial functioning (91). Based on an individual's performance on five neuropsychological tests, participants with MCI (amnestic type) were further characterized into two subgroups: 1) single-domain MCI, if the scores show a deficit only in the episodic memory test. The determination of impairment threshold in memory domain is defined based on criteria by Kochan et al (41) that reflected in scores between ≤ -1.5 SD to > -2 SD (typically impaired MCI), and 2) multiple-domain MCI, if the scores reveal an impairment in the episodic memory test and at least one other non-memory tests. The determination of impairment threshold in non-memory domains is the same level as that in memory domain. The normative value of each neuropsychological test for healthy elders is shown in Table 7.

Table 7 Published norms (Mean ± SD) and the score at 1.5 and 2.0 below SD for five neuropsychological tests in healthy elders (91, 147, 148)

Neuropsychological tests	Age 65-69 yrs			Age 70^{+} yrs		
	Published norm (Mean ± SD)	**Score at 1.5 below SD**	**Score at 2.0 below SD**	**Published norm (Mean ± SD)**	**Score at 1.5 below SD**	**Score at 2.0 below SD**
Logical Memory-Delayed Recall (raw score)	36.5 ± 0.5	35.75	35.5	32.5 ± 0.5	31.75	31.5
Digit Span forward-backward (scale score)	8.6 ± 2.8	4.4	3.0	8.4 ± 2.7	4.35	3.0
Trail Making Test part A (sec)						
-Education 0-12 yrs	39.14 ± 11.84	56.90	62.82	42.47 ± 15.15	65.20	72.77
-Education 12+ yrs	33.84 ± 6.69	43.88	47.22	40.13 ± 14.48	61.85	69.09
Trail Making Test part B (sec)						
-Education 0-12 yrs	91.32 ± 28.89	134.66	149.11	109.95 ± 35.15	162.66	180.25
-Education 12+ yrs	67.12 ± 9.31	81.09	85.74	86.27 ± 24.07	122.38	134.41
Word Fluency (number of word)	17.6 ± 4.7	10.6	8.2	16.1 ± 4.0	10.1	8.1
Block Design (scale score)	7.0 ± 2.5	3.4	2.0	6.4 ± 2.2	3.1	2.0

3.3 Methods

3.3.1 Participants

Sixty older adults aged 60 years or older participated. There were 2 groups of participants; MCI and cognitively intact controls. The participants with MCI were recruited from the Outpatients Department at Suanprung and Maharaj Nakorn Chiang Mai Hospitals, Chiang Mai, Thailand. The diagnosis of MCI was performed by an experienced neurologist. Cognitively intact controls with similar age, gender and education level were recruited from Chiang Mai community. All participants' cognitive function were evaluated by a trained researcher (under supervision of the psychologist) using standard neuropsychological tests.

Inclusion criteria

1) Diagnosis for MCI (amnestic type) based on Petersen's criteria (2) as follows:
   - A self-reported memory complaint, corroborated by an informant interview
   - A score on a standardized memory test rated as 0.5 on CDR
   - Normal general cognitive function, as determined by a clinician's judgment based on a structured interview with the patient and an informant report and adjusted MMSE-Thai version score greater than 23. The MMSE score is adjusted based on age (+ 1 for age ≥ 80 years) and years education (+ 1 for years education < 9) (84, 85).

- No or minimal impairment in ADLs or IADL, as determined by clinical review with the patients and informant interview
- Not sufficiently impaired, cognitively and functionally, to meet NINCDS-ADRDA criteria for AD, as judged by an experienced AD clinician

2) Presence of cognitive impairment determined by the score on the MoCA lesser than 26 (43)
3) Able to walk independently for at least 10 meters without rest
4) Able to comprehend instructions and willing to participate

Exclusion criteria

1) Presence of neurological conditions (e.g. Parkinson's disease, Stroke, Multiple Sclerosis)
2) Presence of depressive symptoms, defined as a score > 12 on the GDS-Thai version (87)
3) Presence of acute or/and chronic disease that could not be controlled (e.g. Arthritis, Asthma, Hypertension, Diabetes mellitus, Coronary artery disease)
4) Uncorrected visual and hearing impairment
5) Taking alcohol 6 hours before testing or using drug regimens that affect gait performance such as sedative and antidepressant

3.3.2 Materials

1) Personal data collection form (Appendix F)

2) Manual and record forms of five standard neuropsychological tests:

   2.1 Logical Memory-Delayed Recall (LM-Delayed Recall)

   2.2 Digit Span (DS) forward/backward

   2.3 Trail Making Test (TMT) A and B

   2.4 Word Fluency (WF)

   2.5 Block Design (BD)

3) GAITRite® system, CIR system, USA

4) Custom-made footswitch system (Force Sensitive Resister; FSR, Interlink Electronics Incorporate, Camarillo, CA, USA)

5) Masking tape

6) Reflective markers

7) Video camera

3.3.3 Independent and dependent variables

Independent variables were:

1) Group: Control group and MCI group

2) Testing Condition: Single-tasking and dual-tasking

Dependent variables were:

1) Gait initiation:

Mean and variability of spatiotemporal gait parameters:

- The first and second step lengths
- The first and second step times
- The first and second step widths

2) Gait termination variables:

- The number of steps taken to stop (stopping response)
- Total stopping time
- Total stopping distance

3.3.4 Procedures

3.3.4.1 Participant characteristics examination

The study protocol was submitted for approval by the Human Ethical Review Board of the Faculty of Associated Medical Sciences and Faculty of Medicine, Chiang Mai University (Appendix G and H). The eligible participants were informed about the study purposes (Appendix J) before signing an informed consent (Appendix K). After that, each participant was interviewed about co-morbidities, medication usage, history of fall in the previous 12 months and fear of falling. The history of fall was assessed by self-report whereas the confidence to perform ADL without fear of falling was examined by Fall Efficacy Scale (FES) (149). For this test, participants were asked to rate their confidence level (range from 1-10) while performing a range of activities of daily living (e.g. reaching into cabinets, walking around the house, getting on and off the toilet) without falling; higher scores indicate poorer confidence. Moreover, participants were objectively examined the risk of fall using Time Up and Go test (TUGT). For this test, participants were asked to stand up from a chair, walk 3 meters, turn around, walk back to the chair and sit down again as quickly but safety as possible. The time taken to complete TUGT > 14.5 seconds is defined as a high risk of future fall (150).

Determination of cognitive profiles

For descriptive purpose, all participant's cognitive profiles (i.e. memory, attention, language ability, executive function and visuospatial function domains) were evaluated using five standard neuropsychological tests including LM-Delayed Recall, DS forward/backward, TMT A and B, WF and BD (detail of administration of each cognitive test has been described previously on page 27-28) (145). Participants with MCI were further classified into two subgroups: single- and multiple-domain MCI based on the scores obtained from the above five neuropsychological tests. If the scores revealed impairment only in the memory domain, the participant was classified as single-domain MCI. In contrast, if the scores revealed impairment in memory and at least one other non-memory domains, the participant was classified as multiple-domain MCI. The determination of impairment threshold in each cognitive domain was defined based on criteria by Kochan et al (41).

3.3.4.2 Equipment and Experimental setup

The spatial gait parameters were measured using the GAITRite® system (CIR system, USA) which comprises a computerized walkway (4.6 m.) and software program. The temporal gait parameters were obtained using a custom-made footswitch system (Interlink Electronics Incorporate, Camarillo, CA, USA). The custom-made footswitch was made by lightweight polymer force sensitive resister (FSR; Interlink Electronics Incorporate, Camarillo, CA, USA). The FSRs were embedded inside a flexible inner sole which was taped to the soles of the shoes. Voltage changes corresponding to heel strikes and toe off were digitized at 100Hz by a portable data acquisition card (NI USB 6008; National Instruments, Austin, TX 78759) and stored on a PC for offline processing. Control of data acquisition and post processing of temporal parameters of gait was performed using the Data Acquisition Toolbox for MATLAB using the algorithm described by Hausdorff et al (151). A digital video camera was located on the side at the middle part of the gait mat in order to obtain a sagittal view of participant. Camera was set parallel to the floor and perpendicular to the plane of motion using a spirit level. The video recording of the participants was used in condition when visual observation was questionable, and then the positional data of the feet was digitized from the foot marker using Silicon Coach 6.0 software program.

Participant preparation

All participants were assessed for baseline secondary task performance by performing loud backward counting by 3 during sitting, starting from a random number between 20-50. The numbers of counting in 1 min as well as the correct answer were recorded. The custom-made footswitches were taped to the soles of the participant's shoes while reflective markers were taped on the medial and lateral side of the shoes.

Protocol

There were two walking tasks (gait initiation and termination tasks) and two walking conditions (single- and dual-task condition), resulting in four testing conditions including gait initiation during single-tasking, gait initiation during dual-tasking, gait termination during single-tasking and gait termination during dual-tasking. The order of single- and dual-task conditions was randomized. Prior to data collection, 2 practice trials were given to allow participants to be acquainted with the walking task. Based on the previous study, gait data recorded from 20 walking trials is sufficient to compute stable spatiotemporal variability during gait initiation (18). Therefore, for gait initiation, each participant performed 20 walking trials for each walking condition as a total of 40 walking trials. For gait termination, to discourage any stopping response anticipation, 12 stopping trials (6 trials for each walking condition) were randomly selected from an overall 40 walking trials.

For the single-task condition, participants were instructed to stand with feet parallel at the beginning of the active area of the mat. They were instructed to start walking as soon as possible in response to an auditory cue and walk at their usual comfortable speed to the end of the gait mat. For the stopping trials, participants were instructed to stop as soon as possible upon the presence of the signal and to remain still until told to continue walking to the end of the gait mat. To control the influence of the stopping cue's timing during the gait cycle on stopping pattern, stopping cue during gait termination was activated only at right heel strike in a random time point during walking (115, 152). For the dual-task condition, all procedures were the same as that of the single task with an exception that participants had to perform the walking task in concurrent with loud backward counting by three from a random number between 20-50. Participants were instructed to start counting out loud at the starting point prior to the auditory cue to commence walking. The number of numerals counted subsequent to the auditory cue as well as the number correct was recorded. There was no instruction to prioritize attention to either the walking or counting tasks (18). During data collection, one tester walked besides the participants to provide support if a loss of balance occurs. Sufficient rest was provided between each trial to prevent fatigue.

3.3.5 Data Analyses

Gait initiation was defined as the first two steps commencing from a starting point (121, 153). For gait initiation, the first and second step lengths and step widths were obtained from the GAITRite system whereas the first and second step times were obtained from the footswitches. Step length (cm) was determined by the distance from the point heel contact of one extremity to the point of heel contact of the next contralateral extremity. Step width (cm) was determined by the horizontal distance between the consecutive footsteps. The first step time (s) was determined by the time elapsed between the heel up of one extremity to the initial contact of the same extremity. The second step time (s) was determined by the time elapsed between the initial contact of the first step to the initial contact of the next contralateral extremity (the second step). The coefficient of variation (COV) was used to determine variability of spatiotemporal parameters during gait initiation by the equation COV = (SD/mean) x 100%. For gait termination, the number of step taken to stop and total stopping distance were obtained from the GAITRite system whereas total stopping time was obtained from the footswitches. Total stopping distance (cm) was obtained by summing the step lengths of the overall steps taken to stop. Total stopping time (s) was obtained by summing the step times of the overall steps taken to stop. Previous studies found that gait speed was expected to influence gait termination performance (154, 155).

SPSS for window version 11.5 was used for data analysis. Independent samples t-test was used to compare the demographic data between the two groups. A 2-Group (MCI, control) x 2-Walking condition (single-task, dual-task) mixed model repeated measures analysis of variance (ANOVA) was conducted to determine significant main effects and interactions. Post hoc analysis was conducted to identify group differences for any significant group effect or group by condition interaction. A probability level of 0.05 was set to denote significance.

3.3.6 Data collection location

The study was conducted at the Faculty of Associated Medical Sciences, Chiang Mai University.

3.4 Results

3.4.1 Participants characteristics

The demographic characteristics of the participants are illustrated in Table 8. Participants in the MCI group walked with slower speed and took more time to perform the TUGT than those in the control group. There was no significant difference between the two groups for baseline secondary task performance in term of the number of numerals counted and the percent of correct responses between the two groups. With respect to the cognitive tests, the MCI group had poorer performance on the MMSE, MoCA, LM-Delayed Recall, DS, and TMT than the control group. Among participants with MCI, ten participants were classified as having single-domain MCI and twenty participants were classified as having multiple-domain MCI.

Table 8 Demographic characteristics of the participants

Variables♦	Control group (n=30)	MCI group (n=30)	*p*-value
Age (yrs)	70.97 ± 7.64	70.60 ± 7.96	0.86
Height (cm)	157.60 ± 7.42	154.90 ± 7.58	0.17
Weight (kg)	56.08 ± 7.95	57.67 ± 8.59	0.46
Educational level (yr)	10.27 ± 4.14	10.93 ± 5.35	0.59
Male: Female	10 : 20	10 : 20	-
At least 1 fall in the past 1 yr	0.33 ± 0.61	0.47 ± 0.68	0.43
Drugs (types)	1.10 ± 1.16	1.80 ± 1.42	0.04*
FES (score)	12.23 ± 16.33	18.90 ± 22.40	0.19
TUGT (sec)	7.09 ± 0.98	8.15 ± 1.60	0.001*
Preferred gait speed (m/s)	1.22 ± 0.20	1.08 ± 0.21	0.01*
Baseline secondary task performance			
- Numbers of numerals counted	21.50 ± 9.80	18.93 ± 7.36	0.26
- Percent of correct responses (%)	90.60 ± 9.94	88.51 ± 12.39	0.48
GDS (score)	2.10 ± 2.63	4.03 ± 2.77	0.01*
MMSE (score)	29.07 ± 0.98	27.63 ± 1.47	0.001*
MoCA (score)	27.37 ± 1.22	21.90 ± 2.67	0.001*
LM-Delayed Recall (score)	41.70 ± 5.45	23.07 ± 8.94	0.001*
DS (score)	16.07 ± 3.41	13.63 ± 2.61	0.001*
TMT (sec)	76.33 ± 38.99	105.27 ± 64.78	0.04*
WF (words)	20.77 ± 3.89	19.20 ± 4.55	0.16
BD (score)	19.43 ± 6.93	16.67 ± 7.28	0.13

♦Data are shown as mean ± SD. FES, total score = 100 points; MMSE, total score = 30 points; MoCA, total score = 30 points; GDS, total score = 30 points; LM-Delayed Recall, total score = 75 points; DS, total score = 28 points; TMT, subtracting part B from part A; BD, total score = 51 points

3.4.2 Gait parameters during gait initiation

Mean spatiotemporal parameters

Repeated measures ANOVA revealed no significant Group x Walking condition interactions or group effects but significant condition effects for all dependent variables (Table 9). Thus adding the cognitive load had a similar effect on all mean spatiotemporal parameters in both groups during gait initiation. Specifically, under the dual-task condition, all participants demonstrated shorter first and second step lengths and reduced first and second step widths compared with the single-task condition ($p = 0.001$). In addition, both groups walked with greater first and second step times compared to that of the single-task condition ($p = 0.001$). No significant differences in the number of numerals counted and the percent of correct responses during walking were found between the two groups.

Table 9 Mean spatiotemporal parameters during gait initiation under single- and dual-task conditions

Variables♦	Control group (n=30)		MCI group (n=30)		*p*-value†		
	Single task	Dual task	Single task	Dual task	Group	Condition	Interaction
First step:							
Step length (cm)	50.15 ± 6.55	47.76 ± 6.68	48.25 ± 5.66	45.39 ± 6.88	0.19	0.001*	0.60
Step width (cm)	52.15 ± 6.11	50.16 ± 6.32	50.65 ± 5.40	48.37 ± 6.49	0.28	0.001*	0.74
Step time (sec)	0.66 ± 0.08	0.76 ± 0.12	0.71 ± 0.14	0.84 ± 0.23	0.09	0.001*	0.49
Second step:							
Step length (cm)	53.43 ± 6.24	50.37 ± 6.91	51.23 ± 6.50	47.55 ± 7.63	0.14	0.001*	0.55
Step width (cm)	54.78 ± 5.84	51.94 ± 6.57	52.82 ± 6.19	49.68 ± 6.97	0.19	0.001*	0.75
Step time (sec)	0.70 ± 0.08	0.84 ± 0.16	0.74 ± 0.15	0.89 ± 0.21	0.22	0.001*	0.59

♦ Data are shown as mean ± SD.

†Group × Walking condition interaction as calculated by using a 2 groups x 2 walking conditions mixed model repeated measures ANOVA.

*Significant difference at $p \leq 0.05$

Variability of spatiotemporal parameters

Repeated measures ANOVA revealed a significant Group x Walking condition interaction for variability of the first ($p = 0.03$) and second step lengths ($p = 0.01$) as well as first ($p = 0.04$) and second step widths ($p = 0.01$) but not for variability of the first and second step times (Table 10). These spatial variability measures were significantly larger in the MCI group compared with the control group under the dual-task but not the single-task condition as revealed by Post-hoc analysis (Figure 2).

Across both walking conditions, variability of the first ($p = 0.02$) and second step lengths ($p = 0.02$) as well as second step width ($p = 0.02$) in the MCI group were significant greater than in the control group. In addition, variability of the first step time ($p = 0.01$) was significantly greater in the MCI group compared with the control group (Table 10).

Adding a dual task during gait initiation showed a similar effect on all spatiotemporal variabilities between the two groups. Under the dual-task condition, participants in both groups showed greater variabilities of the first and second step lengths ($p = 0.001$) as well as first ($p = 0.01$) and second ($p = 0.001$) step widths compared to the single-task condition. In addition, variability of the first and second step times were larger under the dual-task than under the single-task condition ($p = 0.001$) (Table 10).

Table 10 Variability of spatiotemporal parameters during gait initiation under single- and dual-task conditions

Coefficient of variation, %	**Control group (n=30)**		**MCI group (n=30)**		***p*-value†**		
	Single task	**Dual task**	**Single task**	**Dual task**	**Group**	**Condition**	**Interaction**
First step:							
Step length	7.03 ± 2.61	7.44 ± 2.35	8.03 ± 2.37	10.12 ± 4.85	0.02*	0.001*	0.03*
Step width	6.23 ± 2.14	6.48 ± 1.94	6.85 ± 2.31	8.41 ± 4.24	0.06	0.01*	0.04*
Step time	10.29 ± 3.99	14.92 ± 6.87	15.46 ± 5.15	19.97 ± 8.30	0.01*	0.001*	0.94
Second step:							
Step length	6.35 ± 3.20	7.97 ± 4.22	7.18 ± 2.47	11.65 ± 6.00	0.02*	0.001*	0.01*
Step width	5.85 ± 2.57	6.98 ± 3.14	6.50 ± 2.28	9.97 ± 4.73	0.02*	0.001*	0.01*
Step time	7.18 ± 2.62	9.50 ± 4.21	7.22 ± 2.94	11.53 ± 5.18	0.23	0.001*	0.06

†Group × time interaction effect as calculated by using a 2 groups x 2 walking conditions mixed model repeated measures ANOVA.

*Significant difference at $p \leq 0.05$

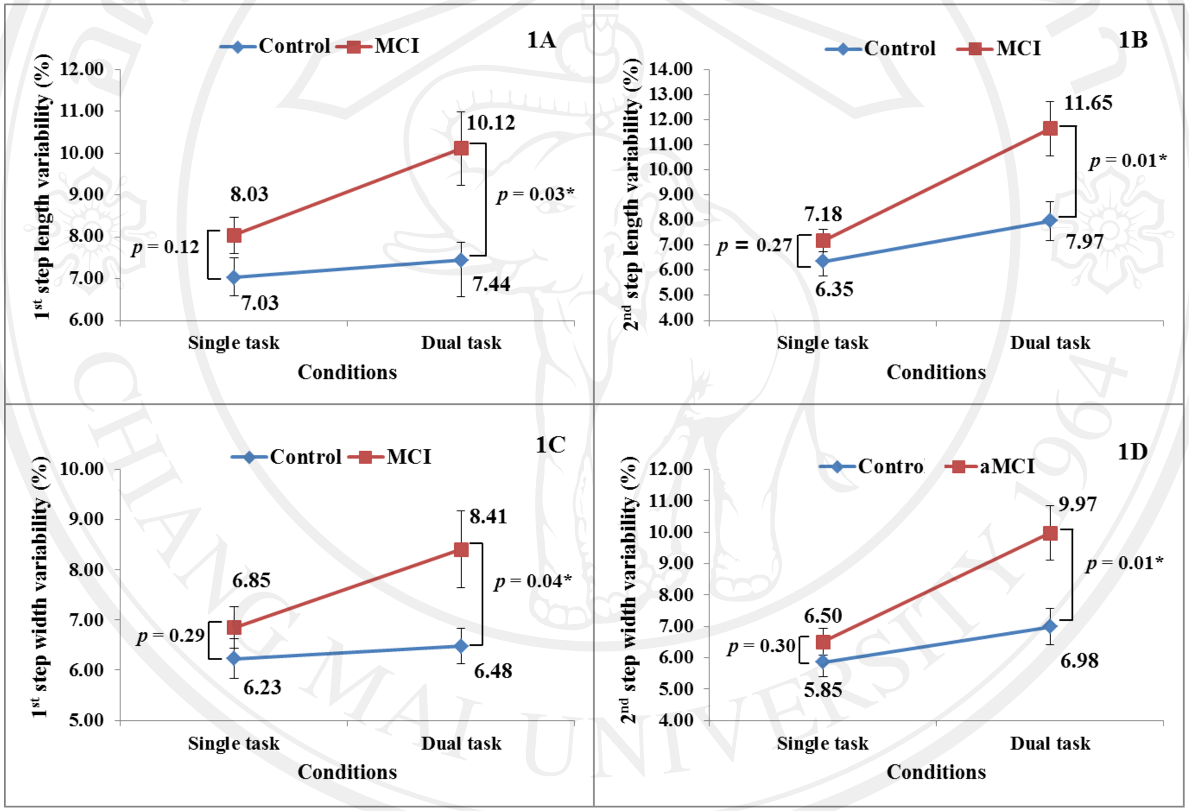

Figure 2 Coefficient of variation of the first step length (1A), the second step length (1B), the first step width (1C) and the second step width (1D) for the MCI and control groups under single-and dual-task conditions. Data are presented as mean ± SEM. *Significant difference at $p < 0.05$

3.4.3 Gait variables during gait termination

Repeated measures ANOVA revealed no significant Group x Walking condition interactions and group effects but significant condition effects for the numbers of steps taken to stop and total stopping time (Table 11). Thus adding the cognitive load had a similar effect on the numbers of steps taken to stop and total stopping time in both groups. Specifically, under the dual-task condition, all participants required lesser steps ($p = 0.03$) and took shorter time to terminate gait ($p = 0.001$) compared to the single-task condition. No significant differences in the number of numerals counted and the percent of correct responses during walking were found between the two groups.

Adding a dual task during gait termination showed a similar effect on gait speed between the two groups (Condition Effects, $p < 0.05$). Specifically, participants in both groups walked at a slower speed under the dual-task condition (MCI group = 0.52 ± 0.16 m/s, control group = 0.56 ± 1.44 m/s), compared to the single-task condition (MCI group = 0.64 ± 0.15 m/s, control group = 0.70 ± 0.12 m/s) ($p = 0.001$). To eliminate the potential effect of gait speed on gait termination performance, all gait variables under the two walking conditions were normalized by gait speed. The results, however, were still persistent after normalization.

Table 11 Gait variables during gait termination under single- and dual-task conditions

Variables♦	Control group (n=30)		MCI group (n=30)		*p*-value†		
	Single task	Dual task	Single task	Dual task	Group	Condition	Interaction
NS	1.89 ± 0.25	1.86 ± 0.30	2.01 ± 0.30	1.88 ± 0.30	0.38	0.03*	0.14
TST (sec)	1.26 ± 0.30	1.12 ± 0.26	1.31 ± 0.27	1.25 ± 0.32	0.07	0.001*	0.97
TSD (cm)	65.13 ± 16.30	58.82 ± 18.41	67.40 ± 19.50	55.23 ± 18.30	0.13	0.17	0.23

♦ Data are shown as mean ± SD. NS, Numbers of steps taken to stop; TST, Total stopping time; TSD, total stopping distance

†Group × time interaction effect as calculated by using a 2 groups x 2 walking conditions mixed model repeated measures ANOVA.

*Significant difference at $p \leq 0.05$

3.5 Discussion

The purpose of this study was to examine gait performance in individuals with MCI during gait initiation and termination, the challenging gait phases, under single- and dual-task conditions compared to cognitively intact controls. We hypothesized that adding cognitive effort during gait initiation and termination would reveal gait changes in individuals with MCI. Our findings are consistent with this hypothesis for gait initiation. Specifically, performing an arithmetic task during gait initiation resulted in a greater level of spatial variability in individuals with MCI than that observed in cognitively intact controls. However, gait variables during gait termination were not significantly different between the two groups either under single- or dual-task condition.

For gait initiation, variability of spatial parameters was significantly larger in the MCI group compared with the control group under the dual-task but not the single-task condition. In every-day life, elderly persons experience situations where they start walking while engaging in other cognitive tasks (e.g. start walking while talking). Previous studies have shown that walking while performing an attention-demanding task compromises a stable gait pattern in individuals with cognitive impairment, reflected via an increase in spatiotemporal variability (21, 98). The underlying premise is that deficits in the ability to divide attention and/or to properly allocate the cognitive resources between concurrent tasks compromise walking stability (98). The significant Group x Walking condition interaction was demonstrated only for the spatial variability but not temporal variability. Previous gait initiation studies that examined spatiotemporal parameters among elderly people with and without cognitive deficits are scarce. Wittwer et al (18) found temporal variability (i.e. stride time and double support time) but not spatial variability (i.e. stride length and step width) to be significantly increased in older people with AD when compared to cognitively intact controls. Conversely, Mbourou et al (119) reported that elderly fallers demonstrated greater spatial variability (i.e. step length) than both elderly non-fallers and young adults. Because of the differences in sample groups, outcome measures, methodologies, and equipment across studies, it is difficult to directly compare these results. However, it appears that cognitive declines due either to ageing or disease contribute to changes in gait control during gait initiation. In addition, the significant Group x Walking condition interaction was shown only for the variability of gait but not mean value measurement. The findings are in agreement with previous studies that have suggested that gait variability is a better clinical index for indicating fall risk than mean gait parameters (98, 156).

It has been suggested that the first two steps of gait initiation are inherently unstable as acceleration is greatest during this phase (157). The first step of gait initiation is used to propel the body from a static state (quiet standing) to a dynamic state (walking) while the second step of gait initiation is used to create an energy input (push off) to raise the body's energy state (157). There is an evidence that gait initiation is governed by a motor program through a stereotyped pattern of muscle activity that produces an external dorsiflexion moment at the ankles to rotate the body forwards over the feet (158). This motor program may be compromised in individuals with MCI. It is also possible that individuals with MCI have trouble initiating the weight shifting during the first step and controlling the rapid energy generation when taking the second step resulting in increased spatial variability in this transitional gait phase. Robinvitch et al (159) investigated real-life falls in elderly people residing in long-term care by using the video capture and found that the most common cause of falls was incorrect weight shifting. In their study, of the 32 residents with video-captured falls, 11 (34%) were diagnosed with AD. Further studies that investigate the center of pressure (COP)-COM distance relationship of older adults with MCI would provide insight into their postural control during gait initiation.

The present study on gait termination found an absence of Group X Condition interaction but significant condition effect. The results did not support our hypothesis that participants with MCI will require more steps and take a longer stopping time and distance to stop more than that of cognitively intact controls under the dual-task condition. One explanation is that these findings may be interpreted that cognitive load had a similar effect on gait variables during gait termination between the two groups. As we found, under the dual-task condition, participants in both groups required lesser steps to stop and took shorter stopping time compared to the single-task condition. It is possible that the reduction in the numbers of steps taken to stop and total stopping time were a product of decreasing of gait speed under the dual-task condition. Previous studies suggested that older adults with-and without MCI exhibited slower gait speed during walking and performing concurrent task compared to walking alone (speed-accuracy trade-off) (14, 96, 160). In the present study, gait speed of both groups (MCI group = 0.52 ± 0.16 m/s, control group = 0.56 ± 1.44 m/s) reduced to almost 50% under the dual-task condition compared to their preferred walking speed (MCI group = 1.08 ± 0.15 m/s, control group = 1.22 ± 0.20 m/s). Thus, this slow speed may allow the participants to achieve a complete stop by taking only few steps and short distance. Alternatively, gait variables may not be sensitive enough to reveal subtle gait changes in individuals with MCI during this gait phase (7). In order to discourage stopping response anticipation in the present study, it is inevitable to randomly select the stopping trials from overall walking trials. Therefore, the numbers of stopping trials were not sufficient for calculating spatiotemporal variability. Future studies on gait variability may further advance our understanding on the changes in gait control during gait termination. To the best of our knowledge, this is the first study that determines gait performance during gait termination between older adults with and without MCI. One previous study found that older adults without cognitive impairment required more steps to stop and took longer stopping time and distance compared to young adults (123). Due to the difference methods across studies, types of stopping cue (i.e. visual cue, auditory cue), and timing to activate stopping cue during the gait cycle, therefore, it is difficult to directly compare these results.

3.5.1 Clinical implications and limitations

To the best of our knowledge, this is the first study that determines gait changes during gait initiation and termination in individuals with MCI both under single- and dual-task conditions. Previous studies have usually investigated gait performance of cognitive impaired persons under steady-state walking (15, 21). However, many falls occur during walks of only short distances in which initiation and termination phases make up a large part (20). Therefore, the findings may advance our understanding on gait changes in individuals with MCI when they encounter a challenging transitional phases. We acknowledge our study has certain limitations. Our participant numbers were not sufficient for sub-group analysis of MCI subtypes (i.e. single- and multiple-domain MCI etc.). As a previous study has reported that motor impairment in individuals with MCI may be specific to the domain of cognitive impairment (15), future studies should investigate gait characteristics in individuals with different MCI subtypes including those with and with impairments to executive functioning (161). In addition, a study design that includes the COP-COM distance relationship would provide insight into postural control of individuals with MCI during gait initiation. Future studies also should include gait variability when investigate gait changes in individuals with MCI during gait termination.

3.5.2 Conclusion

By adding cognitive effort during gait initiation, individuals with MCI demonstrated a significant increase in the variability of step length and step width as compared to cognitively intact controls. These findings suggest that individuals with MCI have an impaired ability to regulate their gait pattern during gait initiation which may predispose them to falls. For gait termination under the dual-task condition, participants with MCI and cognitively intact controls required lesser steps and took shorter time to stop compared to the single-task condition.